

Biogas buses

—

A cost estimate



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Introduction and conclusion

DANINCO has commissioned a short study on the costs for operating CNG/biogas buses, compared to conventional diesel buses. The study is based on the extensive Swedish experience from this kind of buses, with additional information from other countries where CNG buses are operated, though this mainly using non-renewable natural gas.

To use biogas as transport fuel, it has to be upgraded and the upgraded product is often referred to as biomethane. In this report, however, we use the term biogas for both the upgraded and the non-upgraded product. The terms “CNG” and “CNG bus” officially refer to compressed natural gas, though when used in this report they refer to compressed gas, including both natural gas and biogas.

The cost comparison focuses on cost of capital, fuel costs and maintenance costs, but also includes a comparison of societal costs. The comparison is exclusively between diesel and CNG/biogas, mainly based on the Swedish situation. Most conclusions are fairly general, but fuel prices are clearly country-specific, as is Sweden’s relatively long experience of CNG buses and the way this affects costs.

The main conclusions from this report are:

- **CNG buses are by now a mature technology**, meaning lower costs and reduced risk – and that earlier cost comparisons may not be relevant for the future.
- **Cost differences between CNG and diesel buses are now minimal**, since CNG technology has matured. In the future, CNG may become comparatively cheaper since future emissions legislation will likely increase prices for diesel buses.
- **Small fleets mean high costs**, with the lowest cost increases found where the fleets are larger and time since introducing CNG buses is longer.
- **Fuel costs are an important factor**, and vary not only between countries but (in Sweden) between regions and municipalities.
- **CNG buses have significantly lower societal/environmental costs**, especially if using biogas, though there is no universal agreement on this cost benefit.

Conversion sheet

Standard gas density: 0.79 kg/m³

Standard density diesel: 0.835 kg/dm³

Diesel energy content: 42.5 MJ / kg, 35.5 MJ/dm³, 9.8 kWh/l

Natural gas energy content: 10.3 MJ/m³, 11 kWh/NM³

Biogas energy content: 9.7 kWh/NM³

Mattias Goldman, writing this report, was as a locally elected politician involved in the introduction of biogas digesters and biogas buses in Uppsala, one of the first municipalities to run its public transports on sludge and waste. As a spokesperson for Gröna Bilister (the Swedish Association of Green Motorists), he has continued working with biogas for public transport and passenger cars. He is currently developing biogas/biofuel strategies for several organizations.

The Swedish CNG bus market

In Sweden, CNG buses have been used for around 20 years in public transport and currently around 1750 CNG buses are used, more than double the 2007 figure. Almost all of them are for local public transport, used in 30 cities, the largest users being Skånetrafiken, SL and Västtrafik, while Keolis and similar operators are the main owners.

Sweden's fleet of CNG buses is the third largest of Europe, after France (2400) and Italy (2300), and just before Germany and Spain. As a percentage of the total bus fleet, Sweden is by far the market leader, with 17 %, before the Netherlands at 5.4 % and Slovenia at 3.3 %. The European average is 1,7 %. Denmark currently has no CNG buses.¹

Several other countries have larger CNG bus fleets, and CNG buses make up part of urban bus fleets in Beijing, Delhi, Los Angeles, Mexico City, Miami, New York, Pakistan, Paris, Prague, Turin, Vancouver and Zagreb, among other cities.

Sweden has a small fleet of CNG trucks, mainly for refuse, and a few LNG/LBG trucks, but currently no buses running on liquefied gas. Almost all CNG buses are factory built, but a few buses and trucks have been converted. This is also true for the buses and trucks on methane-diesel (MD/MDE), where part of the diesel is replaced with CNG, available primarily from Volvo.

Sales of CNG buses have been very dependent on a small number of buyers/commissioners, and have thus fluctuated very much, depending on their commissions. Over the last few years, with more operators running CNG buses, sales have stabilized but can still vary with close to a 100% from one year to the next, as shown below (information based on BilSweden figures).

Brand	CNG buses delivered Jan-Oct 2011	CNG buses delivered Jan-Oct 2012
Iveco	1	3
MAN	178	100
Mercedes	1	0
Scania	1	50
Volvo	96	44
Total	277	197

As indicated by the sales figures, all of the largest European bus companies now offer CNG buses; apart from the companies in the chart, Neoplan-Solaris also offer CNG buses. This is important, since it secures competition and product development. SL currently uses buses from MAN, Scania and Volvo, and the situation is similar with other public transport companies. About one third of the 1700 buses sold by Neoplan since 1980 are CNG powered, and the demand is growing. Scania has supplied over 3800 CNG buses, even though its main focus on alternative fuels has been ED95 (ethanol buses). In 2012, Scania reached more than 50% of the total Swedish CNG bus market. On the European level, MAN has the largest market share averaging 44 percent over the past eight years.

¹http://www.ngvaeurope.eu/members/2._European_market_shares_Dec_2011.xls for more statistics.

Bus layout

Engine-wise, most producers offering CNG buses use their own engines, converted for CNG use – thus, they are rarely developed for CNG from the outset. The engines commonly used in buses are monovalent, so for CNG usage only, while differ smaller vehicles can also run on petrol. Even though the engine is technically similar to a petrol engine, most major parts (engine block, etc) are shared with the diesel engines to reduce costs.

Companies rarely have more than one CNG engine type, which is typically apt for city transport, for distribution and refuse vehicles. This often means an engine of about 9-12 liters, inline six cylinders, though Scania's engine is five cylinders, and an output of around 200 kW/300hp, and a torque of around 1000 Nm at around 1200 rpm. MAN has engines in five output classes from 162 kW (220 hp) to 228 kW (310 hp). Most CNG buses comply with EEV emission standards and are expected to meet the new Euro 6 engine emissions standards, which come into force in January 2014. Some expect to do this through using an additive such as AdBlue (urea). Engines are typically rear-mounted but some manufacturers also offer front-engined buses, especially for the Latin American and African markets. Total weight doesn't differ much from the diesel buses equivalents, ie around 18 to 30 tons.



The buses are often manufactured close to the main markets; Volvo produces its CNG buses for India in India, MAN produces their CNG buses for the Turkish market in Turkey. Some buses are supplied as chassis by the manufacturers, with separate bodies, though this is more typical for long distance buses.

Over the last few years, technical development has included automatic Transmissions, electronic braking systems, anti-roll, disk brakes, anti-skid protection, hill start aid with grade ability, brake temperature warning and poor brake performance warning. Some manufacturers still offer the CNG vehicles with manual transmission. Top-speed is typically around 70-90 km/h. Gas is stored in tanks located on the roof, typically 6-10 with a capacity of around 205 liters each.



Some manufacturers now offer CNG hybrid buses (the Tata shown is not currently available in Sweden), and Swedish manufacturer Hybricon converts diesel buses to rapid charge plug-in buses with CNG as back-up.

Buses can be single-body or articulated, with up to around 70 seats and a total passenger capacity of over 100, with a total length of 12-18 meters, with Van Hool supplying double-articulated buses of 25 meters. Iveco offers buses for 24 passengers, basically a longer version of their minibuses. Many of the buses are offered in low-floor layout.² The operating life is usually presented as being over 10 years.



CNG buses in public transport

Many local public transport companies have CNG-buses as part of their fleet. Since it is not possible to list them all, the ones seen as the most relevant for CNG Denmark are presented.

Lokaltrafiken Gotland/GotlandsBuss

The small number of buses plus the fact that they were only recently introduced, and that they are directly linked to the investment in biogas production, may make Gotland a relevant example for other start-ups to study.

The "Vision Gotland 2025", developed and decided on by the local and regional authorities, establishes that a high percentage of the energy usage shall be local and renewable, increasing the competitiveness of local businesses. As a long term vision, Gotland strives to become completely energy independent, free from fossil fuels and climate neutral.

² At <http://www.ngvaeurope.eu/buses>, many different CNG bus models are shown

Gotland has produced biogas for many years, and 2010 the Visby water & sewage company was named Sweden's most efficient biogas producer by Svenskt Vatten, which compares how much biogas is produced with how much electricity is used in the water purifying plant.

The municipality ordered CNG buses before any CNG was available, thus ensuring demand and creating the financial conditions for production. On the 9th of September, 2010, the first biogas filling station was established on Gotland, using biogas produced from sewage and sludge. The biogas is upgraded for vehicle usage and is mainly used by the local bus fleet, owned by Region Gotland. All four inner city buses in Visby operate on biogas and a further expansion is planned.

By 2020, the Destination Gotland ferries to/from the mainland are also to be powered by CNG, without any reduction in speed, capacity or frequency. In a first step, the ferries are to be powered by natural gas, later on by biogas from Gotland.

Skånetrafiken

The closeness to Denmark, the relation to agriculture and aggressive long-term plans for biogas make Skånetrafiken a relevant case to study for the Danish biogas sector.

Skånetrafiken is the public transport authority of Region Skåne, with 103 trains, 540 regional buses, 360 city buses and 300 service vehicles. Skånetrafiken's target is to be "much more environmentally friendly than the European average, and completely fossil free by 2020". The focus is "biogas from Skåne from household waste", for the environment and the climate, to ensure steadiness of supply – household waste won't run out – and to create jobs and technical development in Skåne. At the same time, the number of passengers is to increase by 3 % per year.

Skånetrafiken's target is well aligned with the provincial authority, Region Skåne's target of reaching 3 TWh of locally produced biogas by 2020. This demands as much new capacity per year as the current total installed capacity. In 2010, Skåne was named a "pilot province for biogas" by the government, meaning that Skåne has a special responsibility to develop biogas and help other provinces to do the same.³

In all procurements of public transport, gas- and/or electrically powered buses are demanded, and Skånetrafiken has signed long term supply agreements for biogas with several producers in Skåne. In 2011, 54,5 % of all buses run on Biogas, with the local buses in Kristianstad and Eslöv running on 100 % locally produced biogas. In December 2012, 767 out of 1034 buses run on biogas, with the next big step to be taken in 2014. By 2018 Skånetrafiken will operate an estimated 900 CNG buses, using 45-47 million NM3 biogas per year.

Companies operating the bus traffic for Skånetrafiken have to become part owners of the service company for gas buses which operates the terminals where the buses are fuelled and serviced. In this way the terminals are financed and service and maintenance is guaranteed. Skånetrafiken also guarantees residual values for the buses, if operating companies lose the contracts – or they can sell on the buses to new operating companies.⁴

³ <http://www.sweden.gov.se/sb/d/12526/a/146557>

⁴

In November 2012, Nobina, which operates part of Skånetrafiken's traffic, ordered 15 Van Hool ExquiCity "Superbuses" to be used in Malmö from June 2014. The buses are 24 meter long plug-in electric CNG hybrids, Euro6 compliant.

Skånetrafiken sets the extra running cost for CNG buses compared to diesel buses to 7 percent for the period 2012-2020⁵.

SL (Storstockholms Lokaltrafik)

SL is probably the company in the world with the most experience of biogas for buses, and as such their experience is of great relevance to all potential users of biogas buses.

Until the end of 2012, SL is a public transport company owned by the regional authority of Greater Stockholm. From January, 2013, SL will be integrated in the regional authority and no longer operate as a company. SL is part of the regional authority's environmental ambitions, including a target for all public transport to reach 75% renewable energy by 2016. SL aims to reach 100 % renewable fuel by 2025; other parts of public transport such as the ferries to the archipelago find it harder to source appropriate renewable fuels. In 2020, around 500 GWh of biogas is expected to be available in the Stockholm area, of which SL and its operators will use around 40%.

Currently, 58% of SL's busfleet runs on biofuels, through their operating partners. The distribution per fuel is as follow:

- 768 Ethanol buses
- 229 CNG buses
- 211 Biodiesel buses

The ethanol used is ED95, supplied by Swedish Sekab, containing 95% ethanol and 5% ignition provider. The biodiesel used is 100% FAME (RME, from rapeseed), and this is mainly used for outer-city and rural transports in the larger Stockholm area.

The CNG used is a mixture of non-renewable natural gas and renewable locally produced and sourced biogas. On an annual basis, the mix is about 70% biogas and 30% natural gas, depending on production capacity at the municipal biogas facilities.

SL favours the CNG buses from an environmental perspective, judging that it has the lowest CO₂-emissions and by far the lowest emissions of other pollutants, including Nox and PM. On the downside, SL particularly mentions the limited availability and the expensive infrastructure, which leads them to conclude that CNG buses are especially well suited for innercity use.

The current biogas infrastructure for SL:s buses is based on a few production facilities connected to a gas line which in each case supplies one or two of SL:s bus depots. This means that SL is dependent on producers having the capacity to produce the biogas required to drive buses, while the producers are dependent on SL being able to accept the biogas produced, in order not to have to torch the surplus.

⁵ http://www.skane.se/Upload/Webbplatser/Skaneportalen-extern/PolitikPaverkan/Sammantraden/Kollektivtrafikn%C3%A4mnden/Dagordning/2012-05-29/arende_10_dokument_3_bilaga_2_kalkyler_biogas.pdf

The biogas surplus generated at one manufacturing plant may be difficult to use to cover a shortfall at bus depots not connected by the necessary infrastructure. This may mean that the surplus at one bus depot is distributed and sold to public filling stations, while a deficit at another bus depot has to be temporarily replaced by natural gas. Under the so-called “green gas” principle, analogous to the principle of “green electricity”, SL would be credited with the corresponding amount of biogas *not* consumed by its’ buses, minus the natural gas used.

In 2011, SL used 790 530 Nm³ of natural gas for its buses, to cover temporary shortfalls, and sold a biogas surplus of 1 577 344 Nm³ of biogas to AGA, almost twice the amount of natural gas used.

Since 2006, SL has issued several check-points on the economic development by breaking down the costs related to fuels from a total operational point of view. Capital cost, service and maintenance, taxation, fuel costs, distribution and other costs that sum up the differences and pinpoint the strengths and weaknesses of each fuel. After several years of using all fuels, SL claims that from a competitive point of view, biogas seems to provide the most advantages from both an operational and a commercial standpoint. This is explained in more detail in the cost chapter.

Other parts of the Stockholm regional administration are also introducing biogas, including the



world’s first biogas powered ambulance, introduced in 2009 and soon followed by others.

Västerås Lokaltrafik

The Västerås municipality waste company VAFAB, establishes biogas production and CNG filling stations, with the aim that by 2020 all diesel buses in the province of Västmanland will be replaced by biogas.⁶ The Vaxtkraft biogas plant digests bio-waste from households and restaurants, together with ley crops from farms and sludge from grease separators in large-scale kitchens. The biogas that is produced in the process is upgraded for vehicle usage, while the obtained bio-fertilizer is spread back onto the fields as an ecological nutrient by local farmers. The plant provides biogas for at least 40 city buses, 10 refuse collection vehicles and 500 passenger cars, with an upgraded capacity of 100-400 Nm³/h, equivalent to 2,3 million liters of petrol per year. The bus depot has a back-up for at least one day of consumption, with an added, yet to be finished, LNG-storage to replace biogas with natural gas in case of shortage. The buses are run by Västerås Lokaltrafik⁷.

⁶ For a detailed description of the production, see
<http://www.vafabmiljo.se/filarkiv/pdf/vaxtkraft/process%20eng.pdf>.

⁷ http://www.svenskvaxtkraft.se/filarkiv/Pdf/Vaxtkraft/%C3%85rsredovisnVK2011_webb.pdf

The most recent gas station was established in October, 2012, in Köping, where biogas is produced from household waste and locally grown ley crops, complemented by the existing biogas from Västerås.

Until 2016, 10-15 diesel buses will be replaced by CNG-buses annually. From then, existing CNG buses will be replaced by more modern CNG buses. VL expects biogas to be an economically lucrative choice in the years to come, largely thanks to a much lower fuel price than for diesel.⁸

VAFAB's recent investments in biogas production, upgrade to vehicle standard and usage in relatively small local bus fleets makes it a relevance object for further studies.

⁸ http://www.balticbiogasbus.eu/web/Upload/Regional_seminars/Kostnad%20biogas_peter.pdf

Operation costs for buses



First MAN CNG bus, 1943, current MAN CNG bus

Introducing new technologies is almost invariably expensive, and it is often difficult to quantify the cost in a way that's suitable for comparison. This is especially true for biogas buses, where the total cost will be hugely influenced by whether or not the costs of biogas production and distribution are wholly, partially or not at all included. Another determining factor will be whether any value is attributed to reduced emissions of local pollutants and global drivers of climate change. Finally, the cost of the fuel is much more difficult to generalize for biogas than for any established fuel that trades as a commodity, since biogas is locally produced and generally has a local/regional market.

At a general level, CNG buses represent going from the Diesel Cycle to the Otto Cycle, from fairly low exhaust temperatures to high, and from high peak pressure during combustion to low peak pressure. Lean burn combustion is replaced with stoichiometric combustion, switching from oxidation catalyst cleaning technology to three way catalyst systems. While this does not necessarily translate into high costs in the long run, it does mean that initially the learning curve is steep and costly.

Buying and selling

A normal diesel city bus costs around SEK 3,5 – 4 million, though they are often leased on 5-10 year contracts rather than bought. The additional cost for a CNG city bus is about SEK 300 000 – 400 000, corresponding to about 7-10% of the total cost of the bus. The more expensive the basic bus, the lower the additional cost for the CNG will be in percent, since the CNG costs are fairly fixed. Divided over eight years, the added cost is around 50 000 SEK, and if the bus is used 60 000 km/year (typical for a city bus), the added capital cost including interest is around 1 SEK/km, if used 100 000 km/year (typical for intracity buses), the added capital cost including interest is around 0,50 SEK/km. These figures are based on a 5 % interest rate.

The price difference has been significantly reduced over the last few years, and the actual price of any bus is subject to negotiations, and largely depends on configuration, order size and need for maintenance and service. Many operators have also taken advantage of different state and regional schemes that co-finance the extra costs for the CNG buses.

In Sweden, many public transport companies demand that the operators use buses that are eight years old or less, and this age limit is recommended by the public procurement advisory organization Miljöstyrningsrådet. This often means that the buses reach the end of its' operational life with the first operator before they are technically ready to be retired.

The residual value is an uncertain factor for natural gas buses because the second-hand market for these buses is less well defined, though both Swedish and Dutch examples show that both types of buses hold the same value of around 15-20% after eight years of use, 75,000 km per year. For every increase or decrease of 10 000 km the residual value will change around 0.5 %. Many Swedish bus operators put the resale value at SEK 25 000 after 12 years for both diesel and CNG buses, though buses may often not be used for so long.

Many bus operators lease their buses rather than own them, and may no longer need them after a few years, if they fail to win a renewed tender for the public transport. They pay a surplus on the leasing fee for the residual value guarantee; this surplus has been hard to quantify.

In some cases the public transport organization (such as SL) strives to minimize the surplus cost by guaranteeing that the buses may be used even in new tender, so that companies who no longer need their buses are sure that others will be interested in buying them.

Maintenance

When the biogas technology was new, maintenance costs were very high, “boiling engines and toeing buses was daily habits. Spare parts were not in stock, injectors where clogged by silicon-pebbles like materials and lubricants for other type of engines were used”, as Keolis puts it. The heat release from burning biogas increased the wear and tear of valve seat material, valves and seats. During spring and fall, when leaves and other organic material increase in the air, radiators needed to be cleansed daily to avoid boiling engines, while on a hot summer day, the engines would boil. This not only increased costs for repair, but also caused dramatic interruption in fleet accessibility, which increased costs in several ways – the cost for additional vehicles and the fines for non-compliance with transporting contracts.

Several years on, many local transport companies have a high percentage of biogas buses, and the market has grown in such a way so that manufacturers have been able to invest in r&d to develop the CNG buses. The mechanical reliability of the diesel and gas engine is now seen as basically similar, since both types of engines have the same basic engine blocks. For instance, New York City Transit now “expects the CNG buses to have diesel-like reliability and operating costs”.⁹ The same is true for the biogas digester plants, which now have lower downtime than before.

⁹ <http://www.nrel.gov/vehiclesandfuels/fleetest/pdfs/42534.pdf>

However, even with experience and mature products, the maintenance costs are naturally higher for CNG buses than for diesel buses, in much the same way as they are often higher for petrol cars than for diesel cars. Gas engines have special features such as

- Cylinder heads with armored valves and armored valve seats for low abrasion
- Optimized cylinder head cooling, especially good cooling of the spark plug
- Inlet valves with shaft sealing for minimized oil consumption
- Outlet valve guides made from special material with self lubricating quality for low abrasion
- Valve tappets with hard metal plates for low abrasion of the cams
- Special pistons and piston rings for low oil consumption
- Piston rings with special coating for low abrasion
- Bearing shells for con rods and crankshaft with non-abrasive surface
- Water cooled exhaust gas manifold for naturally aspirated engines
- Turbo charger with water cooled bearing house
- Turbo charger equipped with waste gate
- Long life Platinum/Iridium spark plugs
- Exhaust gas after-treatment with a three-way catalyst (at lean operation oxidation only)

The main cost drivers are:

- Spark plugs and ignition cables; replacement needed around every 60 000 km (some report every 25 000 km); often the main extra cost since not needed for diesel. Valve lash adjustment and other fine tuning is generally scheduled to coincide with spark plug replacement
- Diesel injectors may need to be revised after around 500 000 km
- Shorter intervals for changing oil and oil filters (around every 40 000 km, depending on the brand)
- High pressure filters every three years (not needed on diesel buses)
- New Lambda catalyst converters around every 100 000 km (roughly every 18 months, not needed on diesel buses)
- Gas tank insulation checks

Diesel buses, on the other hand, have increased costs for PM catalysts/filters, which need to be changed around every 100 000 km (for inner city buses about once every 18 months). If the filter needs to be sent for cleaning, a spare filter is needed to avoid downtime for the buses, with additional costs. After replacing the filter, a formal inspection may be needed, which may not be costly but means additional downtime.

In total, most estimates put the total maintenance costs for CNG buses at € 0,01/km higher than for diesel buses. Use of biogas does not lead to more maintenance compared to natural gas.

Air conditioning is a belt-driven accessory for all bus groups, and the same seasonal air conditioning load is experienced by diesel, CNG, and hybrid bus groups. While the diesel and CNG buses had conventionally sized engines for a 40-foot transit bus, the hybrids utilize a down-sized engine. Air conditioning load has a more pronounced effect on this smaller diesel powerplant.

Maintenance costs typically represent about 5-10% of the total costs for bus operations, though this is often partially included in sales or lease agreements and vary with the manufacturers. Keolis, which has extensive experience of both CNG and diesel buses, estimate the extra cost for gas buses

to be around SEK 0,5-1,0/km (€ 0,06-0,12), but find that many factors make a direct comparison difficult; depots have different costs, and the CNG and diesel bus models used are rarely even of the same brand. Their cost estimate is based primarily on their work for SL which has a very large fleet; with a smaller fleet of CNG buses, the extra cost is likely to be higher since dedicated material for servicing CNG buses cannot be divided among as many vehicles.

Fuel consumption

Fleet averages for Västtrafik's gas buses show that the total energy efficiency of a CNG motor is around 16 %, compared to just over 20 % for the diesel engine. Thus, the CNG bus consumes 25-30% more energy than the equivalent diesel- or ethanol bus; the efficiency of the ED95 ethanol buses is now almost on par with the diesel, but the CNG is not. The efficiency of the diesel bus remains unchanged if powered by biodiesel (RME/FAME).

Whether the increased consumption translates into increased costs depends on the cost of the fuel. In the Greater Stockholm region, SL and the public authorities have invested in biogas production and guarantee the operating companies a low price. For operators relying on the open market, the situation may be very different, but most operators report a CNG price around 30-35 % lower than the current diesel price. This typically results in over SEK 100 000 per bus in annual fuel cost savings, which means that the higher purchase price is repaid in around 3-4 years, and that the additional maintenance cost are more than outweighed.

Fuel cost example

Diesel costs SEK 11/l, excluding VAT (SEK 1,1/kWh; one liter diesel has 10 kWh) . A city bus consumes around 40 l/100 km, so the fuel cost is SEK 4,4 kr/km. Natural gas costs about SEK 7/Nm³ (SEK 0,63/kWh, one Nm³ has about 11 kWh). The same type of city bus consumes around 65 Nm³/100 km, so the fuel cost is SEK 4,6 kr/km. Biogas costs about SEK 10/Nm³ (SEK 0,9/kWh if one Nm³ has about 11 kWh, the real figure is closer to 10 kWh but 11 kWh is often used). With the same consumption, the cost for this bus is SEK 6,5/km.

This is obviously only an estimate, based on typical urban traffic and a 18-24 meter bus, and the fuel prices publically available in Stockholm. Note that for instance the gas buses used in Lund on average consume just 48 Nm³/100 km, mainly due to being slightly smaller and the traffic being less dense, and for Karlskrona the estimate is 45 Nm³/100 km¹⁰

Especially biogas prices vary widely between different providers, though from any one supplier the prices are generally more stable than the prices of petrol or diesel.

¹⁰<http://www.energikontorsydost.se/userfiles/file/Publikationer/Seminarier/Biogas%20081013/Biogas%20i%20Ostra%20Blekinge.pdf>

Fuel installations



Distributing biogas is expensive, less so in pipelines and more so in container exchange systems. A new installation for fuelling biogas cars typically costs around SEK 3-5 million, while an installation for buses costs about SEK 30-35 million. The costs can be partially mitigated by using the same gas depot for buses, taxis and other vehicles, as FordonsGas does at the Keolis eastern Göteborg depot. This may on the other hand reduce the willingness of private car users to switch to biogas, as the waiting time may be long when using the same equipment and installations.

This is based on the installation being near to existing pipelines for CNG. The cost for distributing and fuelling biogas is calculated by SL to be around € 0,1-0,15/Nm³.

Building the actual digester costs several hundred million SEK, though this is usually not factored in when establishing the additional cost of biogas buses.

Training

While it is not more complex to operate a CNG bus than a diesel bus, it may nevertheless require additional training since most drivers and service personnel are previously trained on diesel but not on CNG. Once CNG is standard business procedure, extra training may only be required when new staff is hired, and even then the time needed is minimal. Drivers are able to operate the fueling facilities for CNG just as they are with diesel.

Garage/parking

Since CNG is explosive, the buildings used for parking and maintenance need methane detectors, mechanical ventilation systems and removal of ignition sources. Some transportation companies recommend having the buildings inspected by the insurance company prior to introducing the CNG buses.

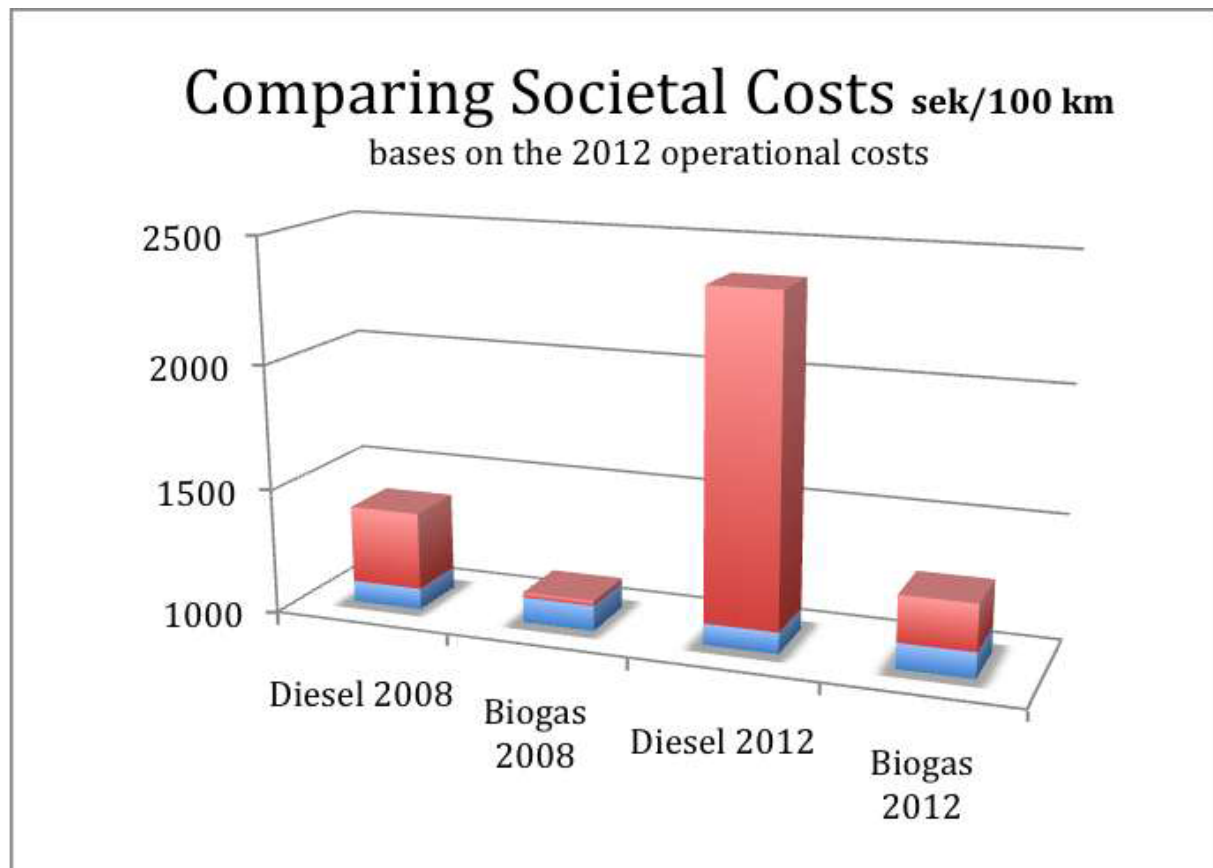
Time loss for fueling

Fuelling a CNG bus can take as little as five minutes, depending on the pressure used. SL however found that such rapid fuelling can lead to oil seeping into the gas system and contaminating it, with extra maintenance as a result. By reducing the pressure and increasing the fuelling time to 8-12 minutes, this problem has disappeared (other reports claim that the problem is due to cheap filling

equipment being prone to oil leakages). Since most buses do not need refueling during the day, this extra time compared to refueling with diesel should not imply any extra cost.

In Sweden, most CNG buses are refueled overnight under low pressure. Since the buses would not be used at night anyway, the time used for refueling this way is not counted as an expense.

Societal costs



Non-monetarized externalities are by definition not included in the normal TCO for transport, and even when they are monetarized (such as the cost for CO₂ emissions), they are rarely included. In order to rectify this, in the late 1990's, Sweden and the EU developed the ASEC- figures to calculate the societal cost for vehicle operations.

In 2010, Swedish Authorities updated their figures on societal costs, with three times higher costs for emissions of climate gases and ten times higher costs for other exhaust gases, compared with ASEC. Using the 2012 operational costs and the 2010 values, in the chart above, it can clearly be seen that the societal costs for biogas are very low compared to those of diesel, with the cost for CO₂ being the main driver (*red* in the chart). The main difference between 2008 and 2012 is the values given to different emissions.

A Dutch estimate of well-to-wheel external costs for CNG buses biogas from manure compared to diesel EEV buses gives the following benefits for CNG:

- NO_x 0,004 €/km

- PM10 0,002 €/km
- CO2e 0,075 €/km
- Total gain 0,092 €/km

Future projection

With the Euro 6 standard for heavy vehicles, emission legislation will be tightened and compliance costs will increase. This is mainly true for diesel-powered vehicles, while the simple chemical composition of biogas should mean that tighter regulations can be met at virtually no cost. This would reduce the cost advantage of the diesel bus, though in most cases only for those buying/leasing the buses after the new legislation is in place.

As for the fuel, diesel can be expected to increase in price over the next years, if the oil price follows or surpasses the IEA long-term projection of 135 USD/barrel. A price increase on many EU markets is further to be expected from the EU decision that all member state must harmonize the taxation between petrol and diesel, in effect meaning that diesel taxation must go up.

The price increases for diesel can partially be mitigated through a blend-in of biodiesels (FAME such as RME) or a full switch to biodiesel, though this in turn depends on tax regulations for biodiesel. Currently, the European biodiesel producers predict that they will have severe difficulties in meeting the requirements of the renewed European Renewable Energy Directive (RED), as proposed by the EU Commission, meaning that future biodiesel availability and pricing on the EU market is uncertain.

As mentioned earlier, biogas for vehicle usage is not a commodity but show a very wide price spread between local markets, including different provinces of Sweden. The pricing is expected to follow that of petrol/diesel, since the producers have little incentive to offer biogas at a price that is significantly lower than that of the established alternative. In Sweden, biogas is currently exempt from energy and CO2-taxation, though this expires after 2013 and the government has not applied for another seven year period of tax exemption. Without this, the biogas market would be severely hampered and may come to mainly depend on public transport providers such as Skånetrafiken demanding biogas usage in their public procurements.

Driver & public acceptance

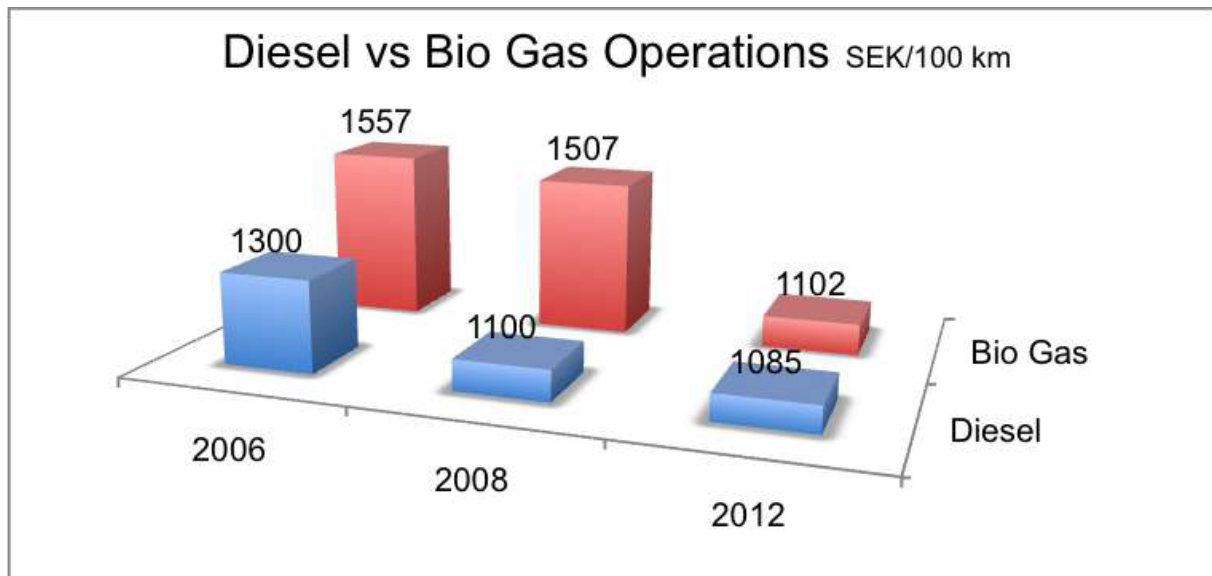
While not generally included in a cost analysis, it is relevant to also look at the driver and public acceptance for CNG buses compared to diesel buses.

The noise reduction of a CNG bus compared to a diesel is around 2-5 dB(A) in normal operating mode, which is clearly audible inside and outside the bus. Reduced vibrations are another benefit that is felt by passengers and may be particularly relevant if using the bus in sensitive environments.

Earlier CNG buses had poorer acceleration than diesel buses, but the difference is now negligible.

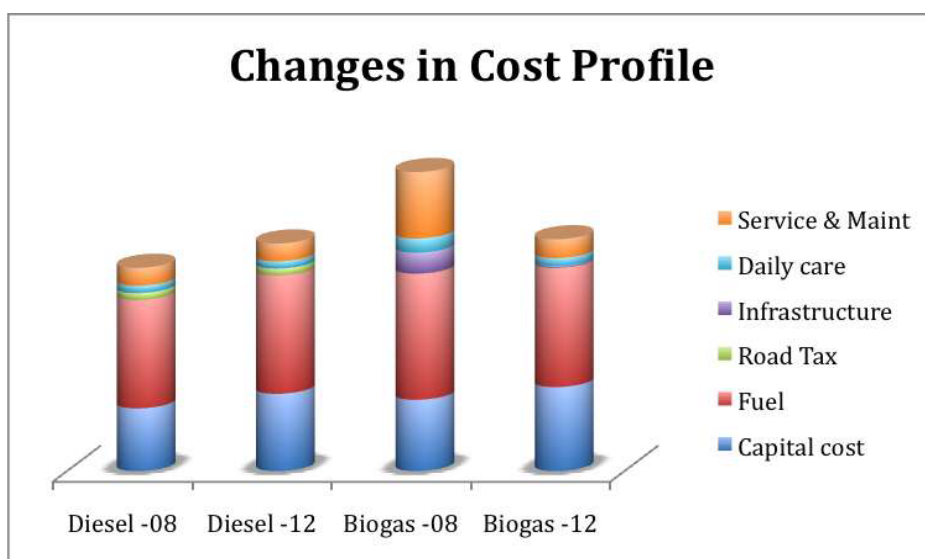
CNG buses have the same number of seats and standing room as diesel buses, and can be ordered with low-floor configuration just as the diesel buses.

Summary: Total cost of ownership



SL:s cost comparison between diesel and biogas buses

According to a SL study, total operation costs for a typical urban/periurban biogas bus are now almost on par with the diesel cost (see chart above). This difference of under 2% is lower than other TCO difference estimates, typically around 5 per cent, and reflects SL's large fleet and long experience with biogas. It may also reflect that SL's diesel buses may not be state-of-the-art. While SL's 40 per cent cost reduction in just four years is impressive, it may also be exaggerated – in the 2008 figure, costs for new infrastructure were included (see below), while in 2012 there was no such need. SL's detailed cost profile for biogas buses further show that the maintenance costs for the CNG buses are now almost down to the levels of the diesel bus, as are the costs for daily care.



SL:s cost profile for biogas and diesel buses

Keolis puts the total extra cost at 0,50-1 SEK/km; the higher price for the bus is around 0,50-1 SEK/km, higher maintenance costs are around 1 SEK/km, while the fuel price is about 1 SEK/km lower. If the total costs for operating a diesel bus are around 20 SEK/km, the added cost for CNG buses is 2,5-5%. If diesel prices go up and CNG/biogas prices don't, the two bus types may soon have the same overall costs (the costs for driver and the basic vehicle, representing about 50% of the total costs, are the same for both alternatives).

Biogas Öst in their calculations put the CNG bus as around 5% more expensive per year than the diesel bus¹¹:

Added cost for CNG bus	300 000 SEK
Interest	5 %
Life span	10 years
Resale value	SEK 25 000
Added cost service/maintenance	SEK 20 000/year
Fuel consumption	47 NM3/100 km, 9,75 SEK/NM3
Fuel cost 100 000 km/year	458 000 SEK
Fuel cost diesel if 39,4 l/100 km 11,48 SEK/l	452 312 SEK

When factoring in the reduced greenhouse gas emission from the biogas buses, the diesel bus is significantly more expensive.

As this report has shown, defining Total Ownership Cost for CNG buses on biogas compared to diesel buses is not straightforward, as costs vary and to a large extent depend on external actors and pricing mechanisms.

¹¹ <http://www.biogasost.se/Portals/0/Regionbussar%20p%C3%A5%20biogas.pdf>